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THE APPLICATION OF THE PENMAN-MONTEITH EQUATION IN PARTIALLY WET CONDITIONS - W SPARKS

1. INTRODUCTION

In a research note Shuttleworth (1976) put forward evidence which he claimed showed that the Penman-Monteith equation in the form:-

$$\lambda E = \frac{\Delta H + (\rho C_p / r_a)\,(e_w\,(T_z) - e_z)}{\Delta + \gamma\,(1 + r_s/r_a)} \quad (1)$$ (conventional notation)

cannot be directly extended to model evaporation from a canopy that is partially wet.

The purpose of this note is to argue that his conclusion stems from an inappropriate circuit diagram of the resistance analogue and that, given a more realistic circuit diagram, his experimental evidence supports the contention that equation 1 can be used to model evaporation from a canopy in any state of surface wetness.

2. SHUTTLEWORTH'S REPRESENTATION OF THE SURFACE RESISTANCE OF A PARTIALLY WET CANOPY

Let r_d be the surface resistance when the canopy is dry, r_w be the surface resistance when the canopy is completely wet and r_s be the effective surface resistance when the canopy is partially wet. Shuttleworth gives histograms of apparent surface resistance observed in Thetford Forest (fig 1) where r_d is typically 100 sm $^{-1}$ and r_w is about 0.005 sm $^{-1}$. He says that r_s is given by the equation:-

$$\frac{1}{r_s} = \frac{W}{r_w} + \frac{1 - W}{r_d} \quad (2)$$

Where W is the proportion of the canopy that is wet. As Shuttleworth points out this equation predicts that r_s will be less than 1 sm $^{-1}$ if the canopy is more than 0.5% wet and, since all the canopies classified as partially wet in his Thetford Forest experiments were certainly wetter than that, the apparent surface resistances of the partially wet group and the completely wet group should not be significantly different. Since they clearly are different (fig 1), either equation 1 or equation 2 does not correctly represent the partially wet condition. The circuit diagram for the transfer of water vapour from a leaf to some level z in the air implied by equation 2 is shown in figure 2. It can be seen that it requires a resistanceless path for the exchange of water vapour from the wet areas to the dry areas at some level close to the surface of the leaf. Generally such a resistanceless path is unlikely to exist.

3. AN ALTERNATIVE REPRESENTATION OF THE SURFACE RESISTANCE OF A PARTIALLY WET CANOPY

As an alternative to the assumption of zero resistance to the horizontal transfer of water vapour between the wet and dry areas an infinite resistance may be assumed. This assumption requires r_a to be represented as 2 resistances, one connecting level z to the dry area and the other connecting it to the wet area. The value of these 2 resistances in parallel must be r_a. The circuit

diagram corresponding to this assumption is shown in figure 3 and r_s is then given by the following equation:-

$$\frac{1}{r_s+r_a} = \frac{W}{r_a+r_w} + \frac{1-W}{r_a+r_d} \qquad (3)$$

The substitution of $r_a = 6$ sm^{-1} (the value used by Shuttleworth), $r_d = 100$ sm^{-1} $r_w = 0.005$ sm^{-1} and various values of W into equation 3 gives:-

TABLE 1

W	0.0	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
r_s	100	52.8	33.8	18.5	11.7	7.8	5.4	3.6	2.4	1.4	0.6	0.005

Such a relationship between W and r_s could be expected to produce the order of magnitude of differences between the effective surface resistances of partially wet and completely wet canopies observed in Thetford Forest.

4. CONCLUSIONS

The Penman-Monteith equation with an assumption of zero horizontal transfer of water vapour between wet and dry areas of a canopy, provides a model of evaporation from a partially wet canopy which is in reasonable accord with observation.

Bristol 16.2.78

REFERENCE

Shuttleworth, W. J. Experimental Evidence for the Failure of the Penman-Monteith Equation in Partially Wet Conditions. Boundary-Layer Meteorology 10, (1976) 91-94.

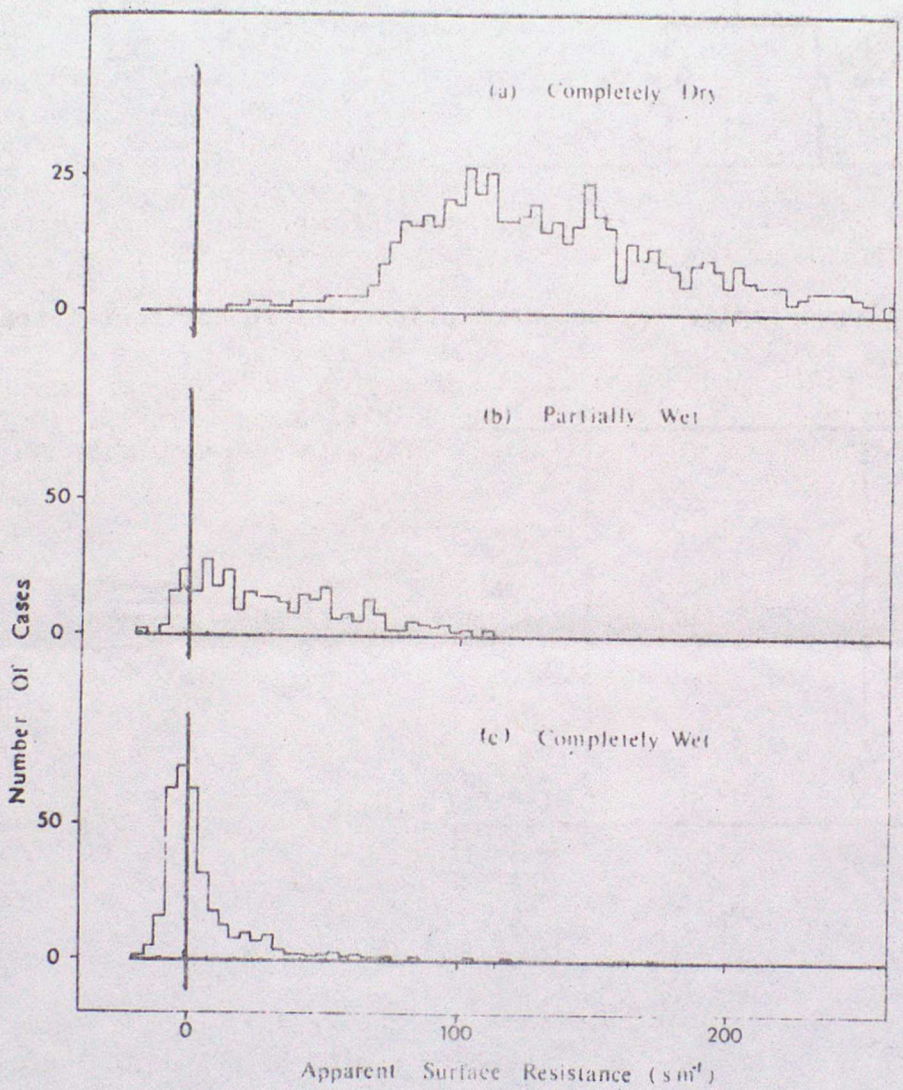

Fig. 1. Frequency distributions of the surface resistance observed in Thetford Forest for (a) completely dry; (b) partially wet; and (c) completely wet conditions.

FIGURE 2

The resistance analogue implied by Shuttleworth's equation for the surface resistance of a partially wet canopy.

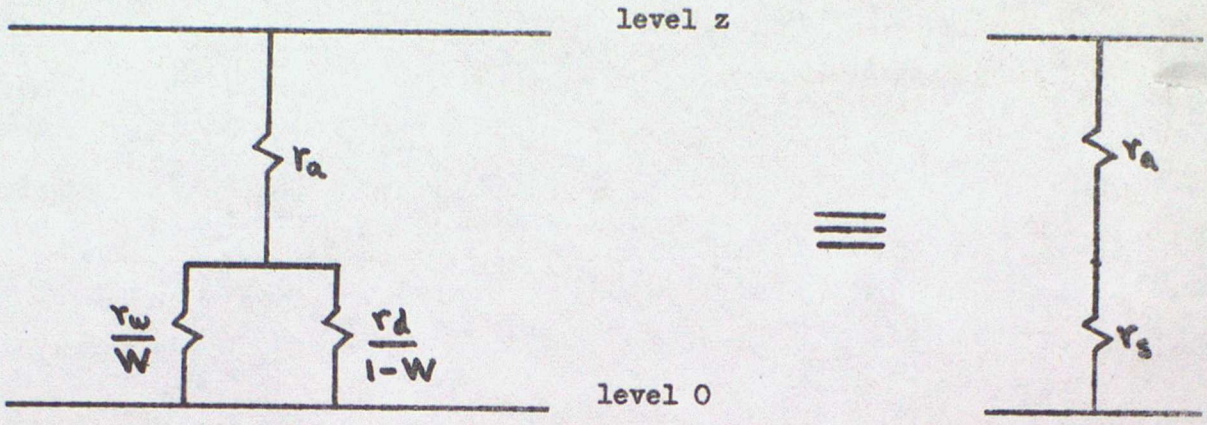

FIGURE 3

The resistance analogue implied by the assumption of zero horizontal transfer of water vapour.